

Effects of Ambient Temperature and Forced-air Warming on Intraoperative Core Temperature

A Factorial Randomized Trial

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ABSTRACT

Background: The effect of ambient temperature, with and without active warming, on intraoperative core temperature remains poorly characterized. The authors determined the effect of ambient temperature on core temperature changes with and without forced-air warming.

Methods: In this unblinded three-by-two factorial trial, 292 adults were randomized to ambient temperatures 19°, 21°, or 23°C, and to passive insulation or forced-air warming. The primary outcome was core temperature change between 1 and 3 h after induction. Linear mixed-effects models assessed the effects of ambient temperature, warming method, and their interaction.

Results: A 1°C increase in ambient temperature attenuated the negative slope of core temperature change 1 to 3 h after anesthesia induction by 0.03 (98.3% CI, 0.01 to 0.06) °C_{core}/(h°C_{ambient}) ($P < 0.001$), for patients who received passive insulation, but not for those warmed with forced-air (-0.01 [98.3% CI, -0.03 to 0.01] °C_{core}/[h°C_{ambient}]; $P = 0.40$). Final core temperature at the end of surgery increased 0.13°C (98.3% CI, 0.07 to 0.20; $P < 0.01$) per degree increase in ambient temperature with passive insulation, but was unaffected by ambient temperature during forced-air warming (0.02 [98.3% CI, -0.04 to 0.09] °C_{core}/°C_{ambient}; $P = 0.40$). After an average of 3.4 h of surgery, core temperature was 36.3° ± 0.5°C in each of the forced-air groups, and ranged from 35.6° to 36.1°C in passively insulated patients.

Conclusions: Ambient intraoperative temperature has a negligible effect on core temperature when patients are warmed with forced air. The effect is larger when patients are passively insulated, but the magnitude remains small. Ambient temperature can thus be set to comfortable levels for staff in patients who are actively warmed. (**ANESTHESIOLOGY 2018; 128:903-11**)

INTRAOPERATIVE hypothermia is common in unwarmed surgical patients¹ and causes serious complications including coagulopathy,² wound infections,³ delayed recovery,⁴ and patient discomfort.⁵ Hypothermia results initially from a core-to-peripheral redistribution of body heat.^{6,7} The second, linear phase of the hypothermia curve results from environmental heat loss exceeding metabolic heat production.¹

Conduction and evaporation probably only contribute about 5% each to intraoperative heat loss, although evaporative heat loss from within surgical incisions remains to be quantified in humans.⁸ Radiation and convection are usually by far the most important heat-loss routes. Radiative loss depends on difference in the fourth powers of skin (~33°C) and room wall (~20°C) temperatures in degrees Kelvin. Convective loss depends on the difference between skin and ambient temperature and the square of air flow at the skin surface. Ambient temperature—the primary determinant of room wall temperature—thus contributes to both major routes of heat loss.

What We Already Know about This Topic

- Intraoperative hypothermia is common in unwarmed patients and can contribute to serious complications. Forced-air warming is a common and effective means to prevent hypothermia. The effect of ambient operating room temperature is poorly characterized for both unwarmed and forced-air warmed patients.

What This Article Tells Us That Is New

- Ambient operating room temperature has a negligible effect on core temperature for forced-air warmed patients, and only a small effect on unwarmed patients.

Forced air is by far the most common type of intraoperative warming, presumably because the approach is effective, easy to use, inexpensive, and remarkably safe. A full-body forced-air cover transfers about 95 watts across the skin surface when the blower is set to “high.”⁹ (Various brands of forced-air warmers appear comparably effective.¹⁰) The difficulty is that a full-body cover cannot be used during most

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surgeries; thus, upper- or lower-body covers are usually used and are about half as effective.⁹ Any insulation or active heating, of course, applies only to shielded areas with loss continuing unabated from the remainder of the body and from within surgical incisions.

While it is apparent that patients in cold operating rooms will lose more heat than those in warmer rooms, the extent to which ambient temperature influences intraoperative core temperature has received surprisingly little attention.^{11–16} Furthermore, the interaction between forced-air warming and ambient temperature has yet to be quantified. We conducted a factorial randomized trial (three ambient temperatures and forced-air warming *vs.* passive insulation) in patients having major noncardiac surgery with general anesthesia to primarily determine: (1) the effect of ambient temperature on the rate of core temperature change from 1 to 3 h after induction of anesthesia (linear phase of the hypothermia curve); (2) the effect of forced-air warming *versus* passive insulation on the rate of core temperature change; and (3) the interaction between forced-air warming and ambient temperature on temperature change. Secondarily, we assessed the effect of ambient temperature and forced-air warming, and their interaction, on redistribution hypothermia (decrease in core temperature during the first hour of anesthesia) and final intraoperative core temperature.

Materials and Methods

The study was approved by the Institutional Review Board at the Peking Union Medical College Hospital (Beijing, China) and written consent was obtained from participating patients. The trial was registered at ClinicalTrials.gov (NCT02715076; February 2016). All patients were enrolled at Peking Union Medical College Hospital. A wide range of semiarbitrary ambient temperatures are currently used at this hospital. Forced-air warming is not routinely used, nor is laminar flow ventilation. In a recent survey of Beijing hospitals, only 11% of surgical patients were actively warmed and 40% had final intraoperative core temperatures less than 36°C.¹⁷

We included adults scheduled for major surgery having redo or bilateral hip arthroplasties, thoracic surgery (usually video assisted), or open abdominal surgery with general anesthesia expected to last at least 2 h. Patients were excluded if they were at special risk for bleeding or myocardial infarction (as determined by the attending anesthesiologist) or would otherwise have been actively warmed. We also excluded patients with a body mass index greater than 30 kg/m². Potential participants were approached by investigators who explained the study and associated risks, and obtained written consent.

Protocol

After consenting, patients were randomly assigned 1:1:1 to ambient temperature of 19°, 21°, or 23°C. Using a factorial approach, patients were also randomly assigned 1:1 to passive insulation or forced-air warming. Randomization was

stratified by the three types of surgery listed in the Materials and Methods paragraph above. Group allocation was based on computer-generated codes (randomly permuted block sizes) prepared by the Department of OUTCOMES RESEARCH (Cleveland, Ohio) statisticians using SAS statistical software (SAS Institute, USA). Allocation of consented patients to designated ambient temperature and forced-air *versus* passive insulation was realized *via* a web site that was accessed by investigators about 90 min before surgery.

Patients assigned to passive insulation were covered as usual with a cotton gown and single layer of cloth surgical draping. Patients assigned to forced-air warming were also covered with a gown and surgical drapes, but a forced-air cover (Bair Hugger 63500, 3M, USA) was inserted between the gown and the skin surface. A lower-body cover (about 91 by 221 cm) was positioned so the lower end of the forced-air segments extended from the ankles upward for the entire length of the cover in thoracic and abdominal cases. The cover's foot drape extended over the feet, and in turn was covered by the surgical drape. Upper-body forced-air covers were similarly applied for patients having hip arthroplasties. The designated forced-air cover was connected to a Bair Hugger blower (3M) set to high (~43°C).

Ambient temperature was adjusted to the designed temperature about an hour before patients entered the operating room and adjusted as necessary to maintain the designated temperature throughout surgery. Patients were not prewarmed. General anesthesia was induced per usual clinical routine. Neuraxial (epidural or spinal) and other regional blocks were permitted. Fluids were not warmed. Any patients whose core temperature decreased to less than 34.5°C was actively warmed with forced air and the ambient temperature increased to the extent practical.

Measurements

Demographic and morphometric characteristics were recorded, along with the primary diagnosis and type of surgery. The study was not blinded because investigators had to actively control ambient temperature and provide forced-air warming when designated.

Ambient temperature was measured with a clinical thermistor probe located well away from any heat-producing equipment and at the height of the patient (typically about a meter from the floor). Sublingual temperature was measured once shortly before induction of anesthesia.¹⁸ After induction, core temperature was measured by a clinical thermistor probe inserted into the distal esophagus. (Clinical thermistors are typically accurate to ~0.1°C even without specific calibration.) In the occasional patient in whom esophageal temperature could not be measured, a nasopharyngeal probe inserted 10 to 20 cm was substituted.¹⁹ Ambient and core temperatures were measured at 10-min intervals throughout surgery, and at the end of anesthesia.

Also at 10-min intervals, we recorded mean arterial pressure, heart rate, and end-tidal volatile anesthetic

concentration. We recorded the time of day at which anesthesia was induced, the total amounts of propofol and opioid given intraoperatively, whether forced-air warming was used, whether neuraxial analgesia was used, and whether rescue warming was required for core temperature less than 34.5°C. We also recorded blood loss and the total volumes of crystalloid, colloid, cell-saver blood, and bank blood.

Data were maintained in a Research Electronic Data Capture Food and Drug Administration–compliant database that incorporates change tracking and version control. The study database was programmed by the Department of OUTCOMES RESEARCH and maintained on secure servers at the Cleveland Clinic (Cleveland, Ohio). Access was *via* a secure web site.

Statistical Methods

We analyzed patient data on an intention-to-treat basis. Demographic and baseline characteristics across the three ambient temperatures and across forced-air warming *versus* passive insulation groups were summarized using descriptive statistics. Time-weighted average of mean arterial pressure, heart rate, end-tidal anesthetic concentration, total amounts of propofol and opioid, use of neuraxial analgesia, and rescue warming during the surgery were also summarized by randomized group.

Our primary aim was to assess the relationship between ambient temperature and slope of core temperature in hours 1 to 3, and to assess whether the relationship differed for those under passive insulation *versus* forced-air warming. We therefore used a linear mixed-effects model to assess the effects of ambient temperature, forced-air warming, and their interaction on the rate of core temperature change during 1 to 3 h after induction. Specifically, we included the ambient temperature by time, forced-air warming by time, and ambient temperature by forced air warming by time interaction terms in the model with core temperatures as outcomes. From this model, we estimated the mean slope of core temperature over time for each group (three ambient temperatures each for passive and forced-air warming) and assessed whether the ambient temperature *versus* slope relationship differed for forced-air warming and passive insulation. Slope and intercept for a patient were considered random effects. Autoregressive correlation was assumed between temperature measurements over time.

Our secondary aim was to assess the effect of forced-air warming on redistribution hypothermia, defined as the difference between baseline sublingual temperature and core temperature at 1 h after anesthesia, using a linear regression model. In addition, we assessed the effects of ambient temperature, forced-air warming, and their interaction on final intraoperative core temperature in a linear regression model, adjusting for baseline sublingual temperature. Interim analyses for efficacy and futility were planned at each 25% of the maximum planned enrollment using group sequential methods: a gamma spending function with gamma being -4 for efficacy and -1 for futility.

Sample Size Consideration

We designed the study to have 85% power at the 0.05 significance level to detect a difference between forced air and passive insulation on the relationship between ambient temperature level and intraoperative core temperature change per hour. In data from a previous warming study we observed a mean (SD) of the increase in temperature during rewarming of 0.011°C/h (0.462) for the combined prewarmed and control groups. We assumed this same SD (0.50) for the current study. We further postulated an ambient temperature positive slope of 0.05°C/h per 1°C increase in ambient temperature for the forced-air group, and 0.15°C/h per 1°C increase in ambient temperature for the nonforced-air group. We needed 345 total patients to have 85% power to detect a difference in slope of 0.1°C/h between the forced-air and nonforced-air groups. Adjusting for planned interim a maximum total of 394 patients across three ambient temperature groups was required.

The overall significance level was maintained at 0.05 across the interim monitoring. Therefore, for this analysis at 75% of the maximum planned enrollment the utilized significance criterion was 0.017 (corresponding to the critical Z of 2.38) after adjusting for interim analyses, for both the primary and secondary analyses. SAS version 9.4 (SAS Institute) was used for the analyses. The full protocol is available by request from the investigators.

Results

Patient Characteristics

Patients were enrolled from February 23, 2016, to December 9, 2016, at Peking Union Medical College Hospital. Because of an oversight independent of any collected data or results, the first two interim analyses were not conducted. The initial interim analysis was therefore conducted after 75% of the planned patients were enrolled. Because efficacy boundaries ($P < 0.017$) were crossed at that time, the study was concluded *per protocol* after enrollment of 295 patients. A total of 292 patients who met the inclusion and exclusion criteria were randomized to one of six groups based on three ambient temperature levels and either passive insulation or forced-air warming. All enrolled patients completed the study and are included in our analysis. Figure 1 is the trial diagram.

The mean ambient temperature measured in the operation room for each patient showed good consistency with the assigned ambient temperature overall (fig. 2). Comparing the mean ambient temperature during surgery and the received forced-air warming to the randomized assignment, 10 patients had mean ambient temperature greater than 1°C deviated from the assigned one, while two patients assigned to forced-air warming received passive insulation instead (Supplemental Digital Content, <http://links.lww.com/ALN/B614>). No patient reached 34.5°C and required rescue warming.

Patient baseline characteristics, surgery type, and intraoperative measurement are summarized in table 1 and do not

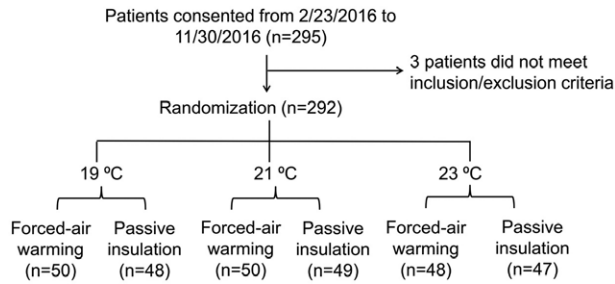


Fig. 1. Flow chart.

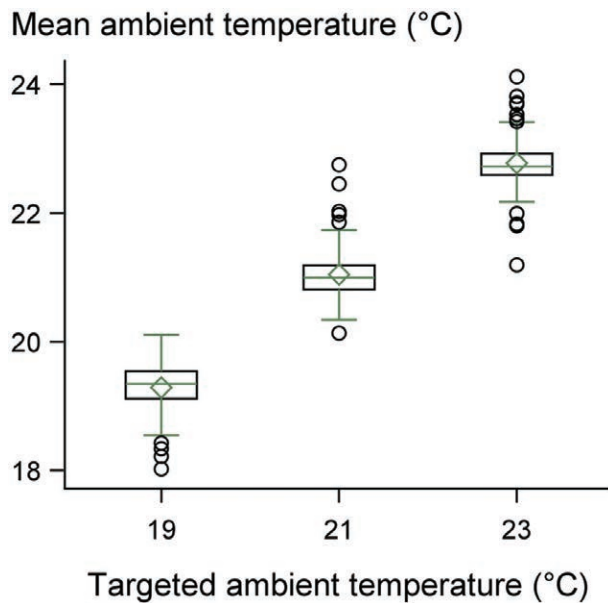


Fig. 2. Mean ambient temperature during surgery by assigned ambient temperature.

show clinically important differences among the six groups. The mean age was 54 yr (SD = 12) and mean body mass index was 24 kg/m² (SD = 3); 51% were men. A total of 5,344 core temperatures from 292 patients were included in our analysis.

Primary Analysis

We plotted the change in core temperature during the initial hour of anesthesia, and then the mean core temperatures at 10-min intervals (fig. 3). The trend of core temperature in each of the six groups between 1 and 3 h was roughly linear. Thus, we used the slope (change in °C/h) to characterize the rate at which intraoperative core temperature changed.

Table 2 shows the estimated rate of core temperature change (slope) from 1 to 3 h as a function of warming and ambient temperature from the mixed-effects model. Descriptively, observed slopes were negative for passive insulation, but less negative as ambient temperature increased, and slightly positive (with no obvious effect of ambient temperature) for forced-air warming.

Ambient temperature affected core temperature change more for passive insulation than for forced-air warming.

Specifically, for passive insulation, there was an estimated 0.03 (98.3% CI, 0.01 to 0.06) °C_{core}/(h·°C_{ambient}) increase in slope of core temperature change per 1°C increase in ambient temperature ($P < 0.001$). However, for forced-air warming, there was no association between ambient temperature and slope change in hours 1 to 3, with estimated change in slope of -0.01 (98.3% CI, -0.03 to 0.01) °C_{core}/(h·°C_{ambient}) for a 1°C increase in ambient temperature ($P = 0.398$). The difference between forced air and passive insulation on this relationship (*i.e.*, significant interaction between warming type and ambient temperature effect) was -0.04 °C (98.3% CI, -0.07 to -0.01) °C_{core}/(h·°C_{ambient}) (interaction $P < 0.001$). The slopes for each of the six study conditions is shown in figure 4.

Secondary Analysis

We then analyzed the change in core temperature in the first hour (redistribution phase) as the difference between baseline sublingual temperature and core temperature at 1 h (table 3). The estimated effect of ambient temperature on temperature change did not differ between passive insulation and forced-air warming ($P = 0.517$). A one-degree increase in ambient temperature was associated with 0.07°C (98.3% CI, 0.01 to 0.13; $P = 0.004$) less reduction in temperature among patients who received passive warming, while there was no association in forced-air group with an estimated effect of 0.05°C (98.3% CI, -0.01 to 0.11; $P = 0.046$ [nonsignificant]).

Last, we assessed the effects of ambient temperature and forced-air warming on the final intraoperative core temperature. As shown in figure 5 and table 4, final core temperatures were higher in the forced-air warming groups than in the passive insulation groups; the core temperatures increased with higher ambient temperature for passive insulation but did not differ for forced-air warming. Adjusted for sublingual temperature shortly before induction, a one-degree increase in ambient temperature was associated with 0.13 (98.3% CI, 0.07 to 0.20) °C_{core}/°C_{ambient} increase in final core temperature for patients who received passive insulation ($P < 0.001$); in contrast, there was no significant association in the forced-air warming groups. The effect of ambient temperature (slope of final temperature across three ambient temperatures) was significantly less for forced-air warming compared to passive insulation, with a difference of -0.11 °C (98.3% CI, -0.20 to -0.02) °C_{core}/°C_{ambient} ($P = 0.005$). After an average of 3.4 h of surgery, the mean core temperature was 36.5°C in each of the forced-air groups, and ranged from 35.6° to 36.1°C in passively insulated patients.

Discussion

Redistribution usually nonlinearly reduces core temperature 0.5° to 1°C depending on the internal tissue-temperature gradient at the time of anesthetic induction and can thus be ameliorated by prewarming.^{20,21} In unwarmed surgical patients, core temperature subsequently decreases linearly, whereas in actively warmed patients, core temperature

Table 1. Demographic and Clinical Characteristics of the Study Sample (N = 292)

	19°C Forced Air (n = 50)	19°C Passive Insulation (n = 48)	21°C Forced Air (n = 50)	21°C Passive Insulation (n = 49)	23°C Forced Air (n = 48)	23°C Passive Insulation (n = 47)
Baseline						
Age (yr)	54 ± 12	50 ± 12	57 ± 11	54 ± 13	54 ± 12	57 ± 11
BMI (kg/m ²)	24 ± 4	24 ± 4	24 ± 4	24 ± 3	24 ± 3	25 ± 3
Male	23 (46%)	19 (40%)	32 (64%)	25 (51%)	24 (50%)	25 (53%)
Type of surgery						
Open thoracic	11 (22%)	13 (27%)	15 (30%)	12 (25%)	15 (31%)	15 (32%)
Open abdominal	39 (78%)	34 (71%)	35 (70%)	37 (76%)	33 (69%)	32 (68%)
Orthopedic	0 (0%)	1 (2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Intraoperation						
Duration (h)	3.4 ± 1.4	3.3 ± 1.1	3.6 ± 1.3	3.4 ± 1.3	3.3 ± 1.5	3.3 ± 1.3
Neuraxial analgesia	7 (14%)	8 (17%)	4 (8%)	8 (16%)	5 (10%)	6 (13%)
Total propofol (mg)	120 (100, 150)	135 (120, 150)	130 (100, 160)	130 (100, 150)	130 (100, 150)	120 (100, 150)
Opioid use (mg)	55 (41, 85)	51 (30, 80)	64 (41, 98)	54 (30, 88)	68 (34, 109)	47 (30, 81)
Sublingual (°C)	36.4 ± 0.3	36.5 ± 0.4	36.5 ± 0.3	36.4 ± 0.4	36.4 ± 0.4	36.5 ± 0.4
TWA HR (beat/min)	73 ± 10	70 ± 9	71 ± 8	70 ± 10	74 ± 11	72 ± 9
TWA MAP (mmHg)	88 ± 9	84 ± 10	85 ± 10	85 ± 8	85 ± 9	84 ± 9
TWA ET sevoflurane (%)	1.3 ± 0.3	1.3 ± 0.4	1.2 ± 0.4	1.2 ± 0.4	1.1 ± 0.4	1.2 ± 0.5

Summary statistics presented as percentage of patients, mean ± SD, and median (Q1, Q3), respectively, for factors, symmetric, and skewed continuous variables. Opioid use is presented as IV morphine equivalent.

BMI = body mass index; ET = end-tidal anesthetic concentration; HR = heart rate; MAP = mean arterial pressure; TWA = time-weighted average.

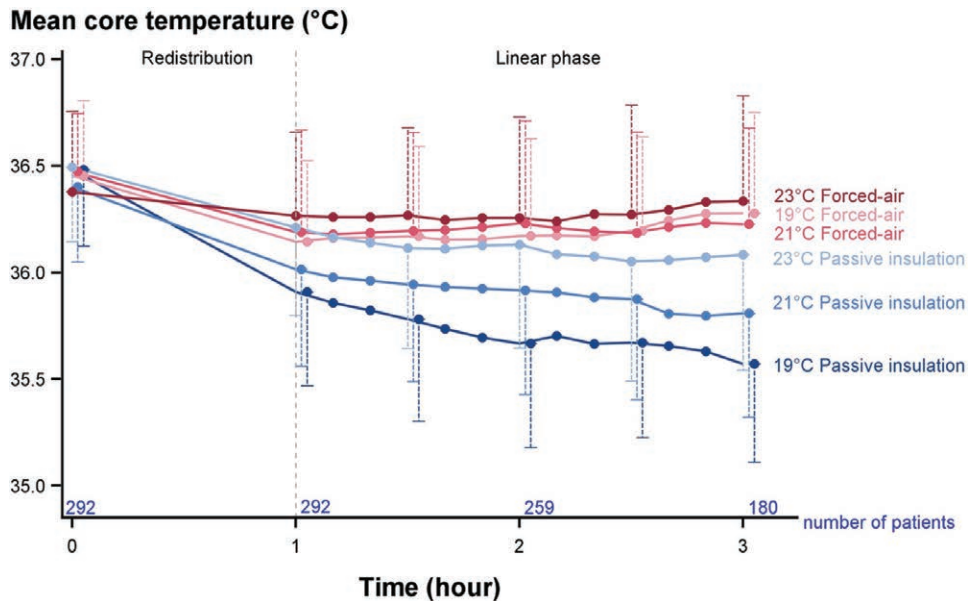


Fig. 3. Core temperatures during the initial 3h of surgery. Core temperature measurements started at various times during the initial hour of anesthesia. Consequently, temperature during the first hour are based on preoperative sublingual temperature and esophageal temperature at 1h. Each line thereafter presents the mean core temperature measured at 10-min intervals as a function of ambient temperature with and without forced-air warming. Half error bars represent the SD at baseline and 30-min intervals from 1 to 3h.

typically increases.¹ The rate of core temperature change during this linear phase of the hypothermia curve depends on the difference between metabolic heat production and heat loss to the environment. The difference, in turn, depends on metabolic rate, size of surgical incision, passive insulation, active warming, and ambient temperature.

Ambient temperature in western noncardiac operating rooms is typically about 20°C, a temperature that nonsurgical

staff typically find a bit cool. Eastern and pediatric operating rooms are typically about 23°C, a temperature that most staff find a bit too warm.²² One of our main results is that, after redistribution, ambient temperature has only a small effect on core temperature in surgical patients covered with passive insulation. Consequently, core temperature after an average of 3.4 h of surgery was only 0.5°C greater in patients maintained at 23°C than at 19°C. Thus, over the range of

Table 2. Rate of Core Temperature Change from 1 to 3 h by Warming and Ambient Temperature (N = 292)

	Ambient Temperature	Slope of Core Temperature Changes \pm SE ($^{\circ}\text{C}/\text{h}$)*	Effect of Ambient Temperature on Slopes (98.3% CI) $^{\circ}\text{C}_{\text{core}}/(\text{h}^{\circ}\text{C}_{\text{ambient}})^{\dagger}$		Forced-air Minus Passive: Difference in Ambient Temperature Effects (98.3% CI) $^{\circ}\text{C}_{\text{core}}/(\text{h}^{\circ}\text{C}_{\text{ambient}})^{\dagger}$	
			Estimate	P Value	Estimate	P Value
Passive insulation	19 $^{\circ}\text{C}$	-0.18 ± 0.03				
	21 $^{\circ}\text{C}$	-0.06 ± 0.03	0.03 (0.01 to 0.06)	< 0.001 ‡	-0.04 (-0.07 to -0.01)	< 0.001 ‡
	23 $^{\circ}\text{C}$	-0.05 ± 0.03				
Forced-air warming	19 $^{\circ}\text{C}$	0.05 ± 0.03				
	21 $^{\circ}\text{C}$	0.07 ± 0.03	-0.01 (-0.03 to 0.01)	0.398		
	23 $^{\circ}\text{C}$	0.02 ± 0.03				

*The slope of core temperature change for each group was estimated from linear mixed model with the interaction effect between ambient temperature and warming on slope of core temperature change. † Effect of ambient temperature, indicating the slope change associated with 1°C increase in ambient temperature, was estimated from linear mixed model with ambient temperature treated as a continuous variable. ‡ Statistically significant. Significance criterion and CIs were adjusted for interim analysis. Correspondingly, $P < 0.017$ was considered statistically significant.

SE = standard error of the slope estimate.

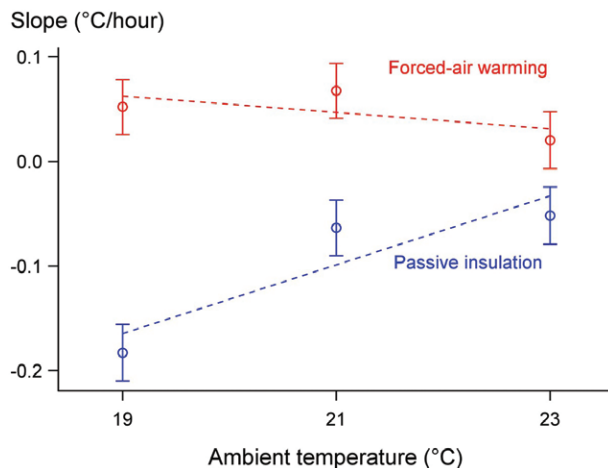


Fig. 4. Slopes of core temperature change from 1 to 3 h after anesthesia as a function of ambient temperature with and without forced-air warming. *Solid circle and bar* represent the estimate and standard error of slopes from the linear mixed model with ambient temperature treated as three categories. *Dashed lines* represent the relationship between slope and ambient temperature from the linear mixed model with ambient temperature treated as a continuous variable. Warmer ambient temperatures reduce the rate at which hypothermia developed in passively insulated patients; in contrast, ambient temperature had no important effect on core temperature during forced-air warming. The slope of the blue line for passive insulation is 0.03 (98.3% CI, 0.01 to 0.06) $^{\circ}\text{C}_{\text{core}}/(\text{h}^{\circ}\text{C}_{\text{ambient}})$, $P < 0.001$, while the slope of the red line for forced-air warming is -0.01 (98.3% CI, -0.03 to 0.01) $^{\circ}\text{C}_{\text{core}}/(\text{h}^{\circ}\text{C}_{\text{ambient}})$, $P = 0.398$.

typical operating room temperatures, core temperature—even after relatively long operations—differed by an amount that is about half the circadian variation^{23,24} and has previously been defined as unimportant.^{18,25}

Our results are qualitatively similar to limited previous information. For example, Morris *et al.*, in three observational studies from the early 1970s, evaluated a total of 84

unwarmed patients ranging from 20 to 85 yr old who had large and small operations in ambient temperatures between 18° and 26°C .^{11–13} More recently, a trial showed that keeping ambient temperature at 21°C rather than at 19°C increased final intraoperative temperature during hepatectomies, but only by about 0.5°C .¹⁴ Benefits of ambient temperatures exceeding 23°C have also been shown in infants.¹⁵ Other studies, though, show little benefit from increasing ambient temperature.¹⁶ A retrospective study also shows, unsurprisingly, that patients stay warmer at higher ambient temperatures.²⁶

Frank *et al.*²⁷ evaluated peripheral vascular procedures under general anesthesia lasting about 5 h; they reported that core temperature was about 0.8°C less when ambient temperature was reduced 3°C , which is very roughly similar to the results of Morris *et al.* and to our results. In contrast, Ozer *et al.*¹⁶ report that body temperatures were similar when ambient temperature was randomly assigned to 20° to 22°C or 23° to 25°C . A limitation of that study, though, is that temperature was measured with infrared aural canal thermometers, which are insufficiently accurate for research. Furthermore, variance of the temperature measurements was not reported. Taken together, current and previous results indicate that ambient temperature is only a moderate determinant of core temperature in unwarmed surgical patients. Maintaining a relatively warm ambient temperature will thus moderate hypothermia in surgical patients who are not actively warmed, but by amounts that are not usually clinically important.

Cutaneous heat loss in undressed adults at an ambient temperature of 21°C is about 100 watts,^{7,28} and increases only slightly after induction of general anesthesia.²⁸ Basal metabolic rate is roughly 80 watts, but decreases about 30% with induction of general anesthesia.⁷ Passive insulation reduces cutaneous heat loss by about 30%,²⁹ but is rarely sufficient to maintain intraoperative normothermia at typical ambient temperatures. Many patients are actively warmed, with forced air being by far the most common approach. These systems reduce radiant loss *via* thermal shielding.

Table 3. Effect of Ambient Temperature and Warming on Slope of Core Temperature Change for the First Hour (N = 286)

	Ambient Temperature	Change in Temperature* ± SD (°C)	Effect of Ambient Temperature on Temperature Change (98.3% CI) °C _{core} /(h·°C _{ambient})†		Forced-air Minus Passive: Difference in Ambient Temperature Effects (98.3% CI) °C _{core} /(h·°C _{ambient})†	
			Estimate	P Value	Estimate	P Value
Passive insulation	19°C	-0.6 ± 0.5				
	21°C	-0.4 ± 0.6	0.07 (0.01 to 0.13)	0.004‡	-0.03 (-0.11 to -0.06)	0.517
	23°C	-0.3 ± 0.5				
Forced-air warming	19°C	-0.3 ± 0.4				
	21°C	-0.3 ± 0.5	0.05 (-0.01 to 0.11)	0.046		
	23°C	-0.1 ± 0.4				

*Change in temperature is the difference between core temperature at 1 h after induction and the baseline sublingual temperature just before administration of intravenous premedication. †Effect of ambient temperature, indicating the change of patient temperature in the first hour associated with a 1°C increase in ambient temperature, was estimated from linear mixed model with ambient temperature treated as a continuous variable. ‡Indicates statistically significant. Significance criterion and CIs were adjusted for interim analysis. Correspondingly, $P < 0.017$ was considered statistically significant.

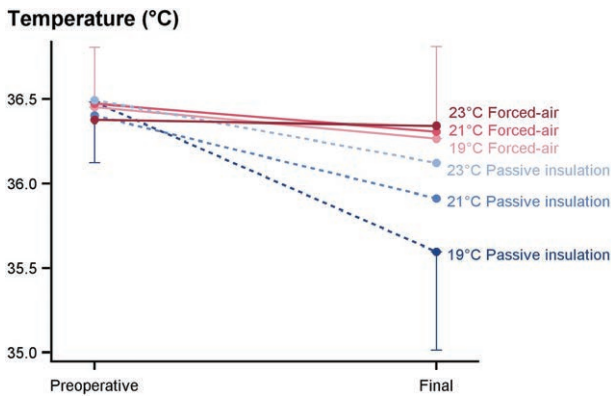


Fig. 5. Core temperature before induction of general anesthesia and at the end of surgery in patients who were or were not warmed with forced air at ambient temperatures of 19°, 21°, and 23°C (47 to 50 patients per group).

Specifically, the warming cover becomes the effective radiant surface, replacing room wall temperature. Since cover temperature exceeds skin temperature, the gradient is reversed and radiation transfers heat into the skin surface. Forced air also ameliorates convective losses by providing a “cocoon” of warm air under the system cover.

Consistent with this theory, our other primary result is that ambient temperature over the relevant range from 19° to 23°C has essentially no effect on the rate of core temperature change from 1 to 3 h after induction of anesthesia for patients with forced-air warming. Nor did ambient temperature have any effect on final intraoperative core temperature in actively warmed patients. These results suggest that forced-air warming, even with half-body covers, creates a microthermal environment around patients, which essentially shields them from ambient temperature. Patients warmed with forced air can therefore be maintained at any ambient temperature between 19° and 23°C without aggravating hypothermia. Operating rooms can thus be kept at

ambient temperatures that are comfortable for staff without any compromise to patient safety.

Redistribution hypothermia results from a large flow of heat from the core to peripheral tissues.⁷ Core temperature usually decreases more quickly during the initial hour of anesthesia than thereafter, as demonstrated in our patients. The variability is also typically greater during the initial hour since redistribution depends on preinduction body heat content and the temperature gradient between the core and peripheral tissues. While it appears that ambient temperature had twice the effect during redistribution as thereafter in unwarmed patients, the redistribution values have greater variance and are less reliable. And importantly, the effect of ambient temperature remains small, even in unwarmed patients. As during the 1- to 3-h period, ambient temperature did not significantly influence the rate at which core temperature decreased in patients who were warmed with forced air—again supporting our conclusion that ambient temperature in actively warmed patients can be set for staff comfort without compromising patient safety.

Our primary outcomes were based on core temperature rather than cutaneous heat transfer or specific measurements of body heat content. But unless there are large changes in skin temperature, changes in core temperature indicate body heat content well.³⁰ Furthermore, core temperature is generally considered the most important single perioperative thermal characterization. Our patients were typically lean (average body mass index of 24 kg/m²). Curiously, though, obesity limits redistribution hypothermia, but has little effect on subsequent core temperature changes.³¹ Obese patients are therefore likely to better maintain core temperature during the initial hour of anesthesia at any given ambient temperature; similarly, they are likely to have higher final intraoperative temperatures. However, our primary observations about ambient temperature and forced-air warming are likely to apply even in obese individuals. Our unwarmed patients were covered with a cotton gown and surgical drapes. To the extent that more insulation is used,

Table 4. Final Core Temperature by Warming and Ambient Temperature Groups (N = 292)

	Ambient Temperature	Final Core Temperature Mean ± SD (°C)	Effect of Ambient Temperature on Final Core Temperature (98.3% CI)		Forced-air Minus Passive: Difference in Ambient Temperature Effects (98.3% CI)	
			Estimate	P Value	Estimate	P Value
Passive insulation	19°C	35.6 ± 0.6				
	21°C	35.9 ± 0.5	0.13 (0.07 to 0.20)	< 0.001†	-0.11 (-0.20 to -0.02)	0.005†
	23°C	36.1 ± 0.5				
Forced-air warming	19°C	36.3 ± 0.5				
	21°C	36.3 ± 0.5	0.02 (-0.04 to 0.09)	0.395		
	23°C	36.3 ± 0.5				

*Effect of ambient temperature, indicating the final core temperature change associated with 1°C increase in ambient temperature, were estimated from linear model with ambient temperature treated as a continuous variable, adjusted for baseline sublingual temperature. †Statistically significant. Significance criterion and CIs were adjusted for interim analysis. Correspondingly, $P < 0.017$ was considered statistically significant.

the small effect of ambient temperature on core temperature would be even smaller.

We studied adults having routine surgery. Hypothermia is more likely in some populations, such as major burns, and ambient temperature may have a greater effect in situations where evaporative losses are especially large. Certain populations, such as pediatric patients, may be at special risk of hypothermia. Generally forced-air warming keeps children normothermic even in cool operating room environments. But ambient temperature should be increased if necessary to maintain normothermia in high-risk patients. For practical reasons, our study was not blinded, but the outcome measure—core temperature—was objective and unlikely to be subject to measurement bias.

An important protocol deviation was that two planned interim analyses were not conducted. This error resulted largely from fast enrollment in Beijing and a delay in getting data to Cleveland. The analysis site (Cleveland Clinic, Cleveland, Ohio) did not appreciate that the analysis thresholds had passed. While unfortunate, this deviation in no way diminishes validity of the study.

In summary, ambient intraoperative temperature has a negligible effect on core temperature when patients are warmed with forced air, apparently because forced air created a cocoon of warm air around patients that effectively became their environment. The effect is larger when patients are passively insulated, but the magnitude remains small with only about 0.5°C difference in core temperature after an average of 3.4 h of surgery over a 4°C range of ambient temperature. Ambient temperature can thus be set to the comfort of the operating room team in patients who are actively warmed.

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3M China (Shanghai, China) provided forced-air warmers and covers for this study.

Competing Interests

Dr. Sessler consults for many temperature-related companies, including 3M; he donates all such fees to charity. The other authors declare no competing interests.

Reproducible Science

Full protocol available at: DS@OR.org. Raw data available at: DS@OR.org.

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